JAN 1947

ARR July 1941

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

July 1941 as
Advance Restricted Report

ALUMINUM-ZINC-MAGNESIUM-COPPER CASTING ALLOYS

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ABSTRACT

The tensile properties and hardness of aluminum-zinc-magnesium-copper alloys containing approximately 0.25 percent chromium and 0.15 percent titanium have been investigated over a range of 0 to 1.75 percent copper, 3 to 13 percent zinc, and 0 to 1.0 percent magnesium. The chromium and titanium were added for their specific effects on resistance to corrosion and grain refinement, respectively. Aluminum ingot which contained approximately 0.15 percent iron, 0.08 percent silicon, and 99.75+ percent aluminum was used as a base. In sand castings, approximately 0.4 percent copper, 6.6 percent zinc, 0.33 percent magnesium, 0.25 percent chromium, and 0.15 percent titanium appear to give a good combination of strength and ductility together with satisfactory resistance to corrosion. Such an alloy ages at room temperature without any previous heat treatment and attains high tensile properties, endurance limit, resistance to failure by impact, and good resistance to corrosion in the accelerated tests utilized in this investigation. Castings of this type of alloy, however, have the disadvantage of being somewhat "hot short." Its tensile properties at elevated temperatures are relatively low, and it overages with the consequent loss of tensile strength and hardness when exposed for a few months at temperatures as low as 212° F. At 300° F this overaging effect is rapid with consequent marked deterioration of the tensile properties and hardness.

ALUMINUM-ZINC-MAGNESIUM-COPPER CASTING ALLOYS

By L. W. Eastwood and L. W. Kempf

Aluminum-base alloys containing a high zinc content were among the first aluminum alloys used for castings. Because they were used in the early years of the aluminum casting industry, particularly in Europe, their history presents an interesting chapter in the commercial development of this metal. The principal early investigation of binary and more complex aluminum-zinc alloys was done by Rosenhain and Archbutt (reference 1) in 1912. An excellent review including an extensive bibliography of the early development of aluminum-zinc alloys was published by the Bureau of Standards (reference 2) in 1927.

The high zinc-aluminum alloys most widely used in Europe contained 10 to 14 percent zinc and 2 to 3 percent copper, largely as a result of the work of Rosenhain and Archbutt. In the United States, Zay Jeffries and William A. Gibson (reference 3) developed an alloy containing 10 to 12 percent zinc, approximately 2 percent copper, and 1 to 1.75 percent iron, which was used quite extensively during the decennium 1920-30. In addition to aluminum-copper-iron-zinc alloys, these investigators in 1919 also patented aluminum-copper-iron-magnesium-zinc alloys, a preferred composition of which was given as 7 percent zinc, 3 percent copper, 0 to 1.5 percent iron, and 0.1 to 0.3 percent magnesium.

Early in 1921, the production of heat-treated castings began (reference 4) in the United States, and their continued development and use has been accompanied by the gradual displacement of the high zinc-aluminum alloys. This replacement by the heat-treated alloys occurred because of their higher tensile properties, lower specific gravity, better casting characteristics, and greater resistance to corrosion.

Aluminum alloys containing zinc and magnesium as the principal alloying ingredients have also been in commercial use. At an early date, William Guertler and Wilhelm Sander (reference 5) investigated and proposed the use of aluminum alloys containing magnesium and zinc in the proportions in which they occur in the compound $MgZn_2$. Alloys of this type have been used commercially for a number of years. (See reference 6.) For example, an alloy known as "Constuctal 8" containing 7 percent zinc, 2.5 percent magnesium, and 1 percent manganese was first produced in Germany about two decades ago. A similar alloy developed by William Guertler for castings, containing 7.6 percent zinc and 1.7 percent magnesium, has been designated G.W.32. Another containing 6 percent zinc, 1.2 percent magnesium, and 2 percent iron was developed by T. S. Fuller and David Basch (reference 7) in the United States.

In 1937 and 1938 a series of United States patents was issued to Yonosuke Matuenaga (reference 8) on aluminum alloys containing zinc, magnesium, and copper as the principal alloying constituents. Aluminum-zinc-magnesium alloys having a preferred composition of 8.0 percent zinc, 0.5 percent chromium, 0.80 percent magnesium, 0.10 percent titanium, less than 0.3 percent copper, silicon or manganese and less than 0.8 percent iron have been proposed by George F. Comstock. (See reference 9.) There have been many other investigations of aluminum alloys containing zinc and magnesium as the principal alloying constituents, but a complete review here is unnecessary.

This paper contains data on the mechanical properties of sand-cast test bars having a considerable range in zinc, magnesium, and copper content and more detailed data on the properties and foundry characteristics of an aluminum-zinc-magnesium-copper alloy having a preferred composition for high strength and ductility. The principal portion of the data is on alloys which also contain approximately 0.15 percent of titanium and 0.35 percent chromium. The titanium and chromium were added because they were found to effect grain refinement and improve resistance to corrosion, respectively.

EXPERIMENTAL PROCEDURE

Preparation of the Alloys

Aluminum ingot containing 99.75 percent aluminum and the alloy components were carefully weighed. The magnesium and zinc were added as such, but the chromium, titanium, and copper were added in the form of aluminum-base riches prepared with 99.8 percent aluminum. The melts were made in plumbago crucibles in gas-fired furnaces. First the aluminum was melted down, and then the alloying material, except the magnesium, was added and melted.

The melt was fluxed with chlorine for 10 to 15 minutes, and then the magnesium was added. If a variation in the content of magnesium, zinc, or copper was desired, these metals were successively added in the proper amounts after each set of the test castings had been poured. Each set of castings in the series was then given the same heat number, with the letters A, B, C, etc., attached in the order of pouring.

Test Castings

Cast-to-size test bars were made using a 6-bar casting, a photograph of which is shown in figure 10. These test bars are 1/2 inch in diameter at the test section. The test-bar castings used for corrosion tests were cast somewhat oversize and machined to 1/2 inch diameter at the test section. A casting having heavy sections was used to determine the effect of section size. This casting is shown in figure 11 with the gates and risers attached. Each section is 6¾ inches long, 4 inches wide, and 1, 2, and 4 inches thick. Test bars 0.505 inch in diameter at the test section were machined from this casting. All castings were poured from 1350° F unless otherwise noted, and all were made in green sand molds.

Aging Treatment

After the castings were made, they were aged as indicated by the data in the tables or figures. Usually the castings were aged for 30 days at a room temperature maintained at about 85° F. In some instances an equivalent aging treatment was effected by using a shorter time at a slightly elevated temperature. This subject is treated more fully elsewhere in this paper.

Corrosion Tests

Corrosion tests were made on separately cast test bars. The investigation of the corrosion of test bars under an applied stress was conducted by using the experimental procedure described by E. H. Dix, Jr. (See reference 10.)

The general corrosion characteristics of unstressed bars were determined in salt-spray exposures in a manner described by E. H. Dix, Jr. and J. J. Bowman. (See reference 11.) The equipment used is illustrated by figures 1 and 3 of their paper "Salt Spray Testing." Hard rubber spray nozzles were employed, and the salt-spray boxes contained six vents each. The air at 40 pounds per square inch was passed through a cleaning tower and then through a water column maintained at 85° F to saturate it at the test temperature before it entered the boxes. The salt-spray exposures, maintained at 85° F, were of two types, continuous and intermittent. A 20-percent-salt solution was used for the continuous exposure and a 3½-percent-salt solution for the intermittent exposure, Morton's Flake Butter Salt being used for both types. The intermittent cycle comprised 16 hours with the box closed and the spray operating, and 8 hours with the box open and the spray not operating.

Six cylindrical test bars made in green sand and machined to 0.5 inch at the test section were suspended from glass rods for each type of exposure. In order to remove dust and grease which might have interfered with the test, the bars were cleaned in petroleum ether before starting the exposures.

Tensile and Hardness Tests

Except those made on heavy sections, all tensile tests were made on separately cast test bars without machining the gage section. Yield-strength values were obtained at the point of 0.2-percent deviation from the modulus line.

Brinell hardness was obtained by using a 500-kilogram load and a 10-millimeter ball.

Elongation values were determined on a 2-inch gage length.

EXPERIMENTAL RESULTS

The experimental results obtained are presented in the accompanying tables and figures. The effects of zinc, magnesium, and copper content on the tensile and hardness properties of cast test bars have been investigated over a considerable range. The resistance to corrosion of these alloys under an externally applied stress also has been investigated. A relatively narrow concentration range of zinc, magnesium, and copper has been more thoroughly investigated in respect to aging characteristics, effects of exposure to elevated temperatures, high-temperature tensile properties, tensile properties in heavy sections, foundry characteristics, and physical properties.

The Effect of Zinc, Magnesium, and Copper Content

The effects of the magnesium content on the tensile strength, percent elongation in 2 inches, yield strength, and Brinell hardness of alloys containing 3 to 13 percent zinc and approximately 0.4 percent copper, 0.25 percent chromium, 0.15 percent titanium, 0.15 percent iron, and 0.08 percent silicon are shown by figures 1a, 1b, 1c, and 1d, respectively. Data on similar alloys containing 1.0 percent copper instead of 0.4 percent are graphically represented by figures 2a, 2b, 2c, and 2d, respectively. A third set of data on a series containing 1.75 percent copper is represented by figures 3a, 3b, 3c, and 3d.

By the use of curves which represent the tensile strength and percent elongation, it is possible to determine the maximum and minimum amounts of magnesium at each zinc content which will give desired minimum values of tensile strength and elongation. This has been done for certain values, and the results are represented graphically by figure 4. This figure shows the range in zinc and magnesium content at which minimum tensile properties of 36,000 pounds per square inch and 10-percent elongation, and 34,000 pounds per square inch and 7-percent elongation were attained under the experimental conditions utilized. The former minimum values of tensile properties are represented by the inside area bounded by full lines, and the latter values by the entire area bounded by the dashed lines.

Examination of figure 4 shows that the higher the zinc content, the lower the magnesium content for maximum combinations of strength and ductility. The shape of the areas representing the zinc and magnesium concentrations for minimum tensile properties of 36,000 pounds per square inch and 10-percent elongation is quite similar at each of the three values of copper content represented. However, increasing the copper content decreases the size of areas representing the range of magnesium and zinc for these minimum properties; and for a given zinc content, increasing the copper requires decreasing magnesium concentration.

Table I shows, for three series of alloys containing 0.4, 1.0, and 1.75 percent copper and 4 to 13 percent zinc, the magnesium content required for the attainment of 36,000 pounds per square inch tensile strength and 10 percent elongation.

As indicated in figure 5, increasing the zinc content increases the tensile and yield strengths and hardness, but decreases the elongation of alloys containing approximately 0.35 percent copper, 0.15 percent iron, 0.08 percent silicon, 0.13 percent titanium, 0.25 percent chromium, 0.27 and 0.29 percent magnesium.

The Effect of Iron and Silicon Content

Iron and silicon may be regarded as impurities since they do not improve the mechanical properties. These elements invariably occur as impurities in aluminum. Accordingly, it is desirable to know the effects of these impurities on the properties. The available data listed in table II, though not extensive, show the effects of iron and silicon separately and in combination. Figure 6 also shows that increasing concentrations of silicon have a very adverse effect on the tensile strength and ductility of alloys containing 0.38 percent copper, 0.15 percent iron, 6.6 percent zinc, 0.13 percent titanium, 0.2 percent chromium, and 0.08, 0.19, and 0.33 percent silicon. Iron alone has only a slightly adverse effect on the tensile properties even when 0.5 percent is present. When iron and silicon are increased simultaneously, the tensile strength and ductility are reduced to about the same extent as they would be if the silicon alone were increased The adverse effect of silicon is probably due to the formation of Mg_2Si which depletes the effective magnesium content and forms a brittle grain boundary constituent. With the aluminum at present commercially available, it probably is not practical to specify silicon concentrations lower than about 0.25 percent. The mechanical properties of commercial castings might be expected to be lower than those obtained in this investigation on alloys containing about 0.08 percent silicon in about the ratio indicated in table II.

Resistance to Corrosion

Four alloys were exposed in salt spray in the manner described above. Two of these alloys contained approximately 7 percent zinc, 0.3 percent magnesium, 0.15 percent iron, 0.08 percent silicon, 0.15 percent titanium, 0.35 percent copper, and 0.00 percent chromium. One of these was prepared from 99.99+ percent zinc, and the other from 99.5 percent zinc. The other two alloys were similar in composition to the first two described, but both were made with 99.99+ percent zinc and both contained 0.25 percent chromium. One of these two contained 0.35 percent copper and the other, 1.0 percent copper. The results obtained after one year of exposure of unstressed cast test bars to continuous and intermittent salt sprays are as follows:

1) The resistance of the alloy containing 0.25 percent chromium is superior to that of the chromium-free alloy.

2) The alloy containing 1.0 percent copper appeared inferior to that containing 0.35 percent copper.

3) The resistance to this type of corrosion is not noticeably affected by the degree of purity of the zinc.

4) An alloy containing approximately 0.35 percent copper, 0.15 percent iron, 0.08 percent silicon, 7.0 percent zinc, 0.15 percent titanium, and 0.25 percent chromium has good resistance to this type of corrosion; it is about equivalent to the well-known Alcoa no. 43 alloy consisting of aluminum with 5 percent silicon.

It has also been found that bars stressed at 75 percent or less of the yield strength are not subject to intergranular corrosion when continuously immersed in a solution of NaCl and H_2O_2, provided the zinc does not exceed about 7.0 percent and the copper is not less than 0.25 percent or more than 0.6 percent.

Preferred Composition

On the basis of the results on tensile properties and resistance to corrosion discussed above, an alloy containing approximately 0.4 percent copper, 0.15 percent iron, 0.08 percent silicon, 6.6 percent zinc, 0.33 percent magnesium, 0.15 percent titanium, and 0.25 percent chromium was selected for more detailed investigation.

Aging Characteristics

Table III and figure 7 show the changes in tensile properties and hardness of cast test bars of an alloy containing 0.38 percent copper, 0.17 percent iron, 0.08 percent silicon, 6.88 percent zinc, 0.12 percent titanium, 0.27 percent magnesium, and 0.23 percent chromium. Three different aging temperatures were used, that is, 85°, 165°, and 212° F. The curves of figure 7 show that the best combination of tensile strength and ductility is attained by aging at 85° F. It will be noted that 1 week at 165° F is approximately equivalent to 1 month at 85° F. This alloy overages even at 212° F when the time at temperature is of several months' duration. Overaging manifests itself by a greatly reduced ductility and some drop in yield strength and hardness. After 3 months at 165° F, there is no softening noticeable, but the ductility as measured by the percent elongation is greatly reduced. This might be compensated by starting out with a lower magnesium content and higher initial ductility.

Tensile Properties in Heavy Sections

Table IV contains data on the tensile properties in heavy sections of an alloy having about the preferred composition referred to above. These data clearly show that a very high percentage of the properties obtained in separately cast test bars is obtained in bars machined from this 18-pound casting having sections 1, 2, and 4 inches thick.

High-Temperature Tensile Properties

The tensile strength and elongation of an alloy containing 1.06 percent copper, 0.16 percent iron, 0.08 percent silicon, 6.89 percent zinc, 0.13 percent titanium, 0.26 percent magnesium, and 0.27 percent chromium at 200°, 300°, 400°, 500°, and 600° F are shown by the data in table V. The elongation at room temperature for the particular lot of test specimens used for the determination of these data and those of table VI, referred to in the next paragraph, is lower than normal for some unknown reason. Nevertheless, the conclusion is probably justified in that the high temperature properties of this type of alloy are somewhat inferior to those of many present day commercial aluminum-casting alloys.

Effect of Prolonged Exposure at 300° and 400° F

Table VI shows the effect of prolonged exposure at 300° and 400° F on the tensile and hardness properties of the alloy referred to in the preceding paragraph. These data show that exposure to such temperatures has an adverse effect on the room-temperature tensile properties because of the overaging effect.

Effect of Exposure to a Temperature Near the Melting Point

Aluminum-zinc-magnesium-copper alloys can be reheated to temperatures near the melting point without a marked adverse effect on tensile properties. Table VII shows the effects of reheating a specific alloy to temperatures from 900° to 1120° F, air cooling, and re-aging at room temperature. These data show that reheating to 900° F has a slightly adverse effect on the tensile properties, whereas reheating to 1050° to 1120° F does not affect the tensile properties. Of course, when this alloy is reheated to such temperatures, the tensile properties are about equivalent to those obtained immediately after casting, and re-aging is necessary to restore them. The amenability of these alloys to reheating to a high temperature makes them attractive for use in furnace-brazed assemblies.

Mechanical and Physical Properties

Using the experimental conditions outlined, an alloy containing approximately 0.35 percent copper, 0.15 percent iron, 0.08 percent silicon, 6.6 percent zinc, 0.15 percent titanium, 0.33 percent magnesium, and 0.25 percent chromium may be expected to have approximately the following mechanical and physical properties in separately cast test bars poured in green sand and aged 30 days at 85° F.

Yield strength	21,000 pounds per square inch
Tensile strength	36,000 pounds per square inch
Elongation	10 percent in 2 inches
Brinell hardness	66 to 70
Endurance limit	7500 pounds per square inch*
Charpy impact value	3.5 foot pounds**
Solidification range	652° C (1266° F) to 610° C (1130° F)
Specific gravity	2.81
Electrical conductivity	29.5 percent I.A.C.S.

Inasmuch as iron and silicon concentrations of 0.15 percent and 0.08 percent, respectively, probably cannot be maintained in ordinary foundry practice with aluminum of the purity at present generally available, it is to be expected that minimum specification values for mechanical properties of this type of alloy must be considerably lower than those given in the foregoing. The highest-purity aluminum-casting alloys at present in commercial use are produced to maximum silicon concentrations of about 0.25 percent. Under similar conditions, it is believed that this type of alloy could be produced to minimum tensile specifications of 30,000-pounds-per-square-inch tensile strength and 6-percent elongation. The properties of the alloy are much less sensitive to iron concentration, and a maximum somewhere between 0.5 percent and 0.75 percent probably will be found permissible.

Microstructure

The microstructure of the aluminum-zinc-magnesium-copper alloys are illustrated by the photomicrographs

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*R. R. Moore rotating beam type of machine, 500,000,000 cycles.

**Modified Charpy impact machine, 10 mm × 10 mm keyhole type, drilled and sawed, notched specimens, section back of the notch 5 mm × 10 mm, 5.07-pound hammer.

(figs. 8a, 8b, 8c, and 8d). The compositions of the alloys photographed are given in the captions to these illustrations. Figures 8a and 8b show similar specimens cut from the cope side of 4-inch sections of the step casting illustrated by figure 10. The alloy shown in figure 8a contained 1.05 percent copper, while that in figure 8b contained 0.34 percent copper. In figure 8a the dark areas brought out by Keller's etch (reference 13) are rich in copper and they also contain light particles of $CuAl_2$ precipitate. The lower copper alloy shown by figure 8b does not have a noticeable amount of copper segregation. Such structures are usually accompanied by superior tensile properties in heavy sections or in castings otherwise subjected to abnormally slow solidification. This type of structure also appears more resistant to corrosion than one exhibiting particles of copper constituent. There is a considerable difference in the grain size between the two specimens of figures 8a and 8b, probably due in part to the higher titanium in the finer-grained specimen and in part to the inevitable variations in the structure of castings. However, the specimens illustrated are fairly typical of the effects of the amount of copper content on the microstructure in heavy sections. In chilled sections or light sections where solidification is more rapid, this type of copper segregation is less pronounced.

In general, the high-purity alloys of the composition photographed consist essentially of a solid solution which is subject to precipitation hardening at low temperatures. Only a very small amount of visible undissolved microconstituents occur. The principal microconstituents which form visible particles in alloys of the composition photographed are the Al-Fe-Si constituent which usually occurs at the grain boundary, but it may not occur in the typical "Chinese script" form, probably because of its small amount. A very small amount of $CuAl_2$ particles occur within the grain or at the grain boundaries where the final solidification took place. Some Mg_2Si particles, recognized under the microscope by their bluish color, occur as isolated particles or in conjunction with the other constituents. The constituents in the alloy have been identified by the methods outlined by E. H. Dix, Jr. and F. Keller. (See reference 13.)

Foundry Characteristics

Although the foundry experience obtained on an aluminum-zinc-magnesium-copper alloy having the preferred composition mentioned above is not extensive, some estimate of their foundry characteristics can be made.

It has been well established that the tensile properties of test bars or of bars machined from 1-inch sections are not affected by pouring temperatures between 1300° and 1450° F. When the pouring temperature is lowered to 1250° F or raised to 1500° F, a very slight decrease in tensile properties occurs.

The fluidity at 1350° and 1450° F has been determined in the manner formerly described (reference 12) and found to be somewhat inferior to many aluminum alloys now in use. However, this difficulty can be offset by employing a slightly higher pouring temperature since no adverse effect is encountered by this procedure.

Data on tensile properties in heavy sections have already been presented, and it was previously noted that a high percentage of test-bar properties is obtained.

The alloy must be well risered to prevent shrinkage, but in this respect it does not differ from some alloys now in commercial use.

The foundry characteristic which probably would cause the most trouble is hot-shortness. In this respect it is about as subject to hot-cracking as some of the aluminum-copper alloys now in use. Therefore, very intricate types of castings might be expected to be difficult to produce in this alloy.

Welding and Brazing Characteristics

It has been pointed out that the alloy having the preferred composition is not adversely affected by heating to a temperature near the melting point if it is allowed to re-age subsequently. Furthermore, the high-tensile properties of this alloy are attained without heat treatment so that, in consequence, it can be welded as readily as the other as-cast alloys and will still retain its high-tensile properties. The alloy also is readily furnace-brazed, since a brazing temperature up to 1100° F can be used. Accordingly, this aluminum-zinc-magnesium-copper type of alloy presents the possibility of utilizing welded and brazed assemblies of castings having exceptionally high strength, toughness, and resistance to corrosion.

SUMMARY

The tensile properties of aluminum-zinc-magnesium-copper alloys have been determined over a range of 0 to 1.75 percent copper, 3 to 13 percent zinc, and 0 to 1.0 percent magnesium. An alloy containing 0.4 percent copper, 0.15 percent iron, 0.08 percent silicon, 6.6 percent zinc, 0.33 percent magnesium, 0.25 percent chromium, and 0.15 percent titanium appears to have the maximum combination of strength, ductility, and resistance to corrosion and has been investigated in greater detail.

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TABLE I

THE MAGNESIUM CONCENTRATION AT VARIOUS ZINC AND COPPER CONTENTS FOR ATTAINMENT OF 36,000 PSI. TENSILE STRENGTH AND 10% ELONGATION

	0.4%Cu	1.0% Cu	1.75%Cu
	Optimum Magnesium Content		
% Zn	% Mg	% Mg	% Mg
5	0.54	-	-
6	0.42	0.41	-
7	0.31	0.29	.16
8	0.20	0.15	.07
9	0.12	0.06	.02
10	0.07	0.02	.01
11	0.04	0.005	.005
12	0.005	-	-

TABLE VI

THE EFFECT OF EXPOSURE TO 300°F AND 400°F ON THE ROOM TEMPERATURE TENSILE PROPERTIES OF CAST TEST BARS OF AN ALLOY CONTAINING 1.06% Cu, 0.16% Fe, 0.08% Si, 6.89% Zn, 0.13% Ti, 0.26% Mg AND 0.27% Cr

Treatment	Properties			
	Y.S.	T.S.	%EL.	BHN
6 Mo. at R.T.	27800	38400	5.5	82
2 " " " + 100 days at 300°F + 2 mo.* at R.T.**	20200	28050	5.7	60
2 " " " + 50 " " 400°F + 3 " " "	13700	26600	7.7	54

*Mo. = Months
**R.T. = Room Temperature

TABLE II

THE EFFECT OF IRON AND SILICON CONTENT ON THE TENSILE PROPERTIES OF TEST BARS OF Al-Zn-Mg-Cu-Ti-Cr ALLOYS

Heat No.	Aging Time	Cu	Fe	Si	Zn	Ti	Mg	Cr	Y.S.	T.S.	%El.	BHN
	Section A											
	Effect of Silicon Content											
555	30 days at 85°F	0.32	0.14	0.08	6.65	0.13	0.33	0.24	21700	38200	12.8	73
556	" "	0.37	0.14	0.19	6.58	0.13	0.32	0.20	21600	34900	10.2	70
557	" "	0.37	0.15	0.33	6.51	0.13	0.33	0.22	23100	33950	6.2	74
063A	" "	0.003	0.24	0.08	6.80	0.18	0.31	0.00	21800	35200	9.5	74
B	" "	*	*	0.18	*	*	*	0.00	20000	31800	8.2	69
C	" "	*	*	0.30	*	*	*	0.00	19800	30000	6.3	70
	Section B											
	Effect of Iron Content											
062A	30 days at 85°F	0.003	0.29	0.10	6.91	0.15	0.28	0.00	22000	36200	10.2	74
B	" "	*	0.46	*	*	*	*	0.00	21600	36600	10.7	74
C	" "	*	0.56	*	*	*	*	0.00	20400	35300	9.0	73
	Section C											
	Effect of Ingot Purity											
067	30 days at R.T.**	0.01	0.11	0.12	7.06	0.16	0.37	0.00	23100	36300	9.0	74
069	" "	0.01	0.33	0.16	7.13	0.16	0.36	0.00	22300	34100	7.3	74
409	" "	0.30	0.16	0.07	6.98	0.18	0.26	0.23	20300	36600	13.3	69
413	" "	0.27	0.23	0.10	7.00	0.18	0.26	0.25	20200	35350	11.7	69
410	" "	0.32	0.30	0.14	6.96	0.19	0.27	0.24	20300	34900	9.8	69
412	" "	0.32	0.32	0.14	6.95	0.23	0.30	0.24	21000	35200	9.2	70

*The chemical analysis may be assumed to be approximately the same as the A sample except as noted.
**Room temperature.

TABLE III

THE CHANGE IN TENSILE PROPERTIES OF CAST TEST BARS OF AN Al-Zn-Mg-Cu-Ti-Cr ALLOY WITH AGING TIME AT VARIOUS TEMPERATURES

Heat No.	Aging Treatment	Y.S.	T.S.	%El.	BHN
559*	1 hour after casting	6550	20875	21.2	34
"	3 days at 85°F	15375	30425	13.3	56
"	7 " "	17575	33350	13.8	61
"	31 " "	20325	35575	10.5	66
"	60 " "	21250	35800	10.7	73
"	90 " "	21925	35925	9.5	72
"	182 " "	23100	37850	11.5	74
"	307 " "	23200	37800	10.5	72
"	1 hour after casting	6550	20875	21.2	34
"	2-1/2 " at 165°F	10675	24675	16.8	43
"	19 " "	17100	31500	13.7	61
"	68 " "	20975	33550	10.7	69
"	6 days "	23675	35850	10.0	70
"	10 " "	24600	36250	9.0	70
"	14 " "	26600	37375	9.2	77
"	21 " "	26600	37700	8.3	77
"	31 " "	28000	37100	6.7	80
"	45 " "	28450	37900	7.5	79
"	60 " "	28800	38500	7.7	86
"	90 " "	30000	38525	6.2	84
"	1 hour after casting	6550	20875	21.2	34
"	3 " at 212°F**	10825	23875	14.0	41
"	20 " "	17125	28725	9.5	56
"	69 " "	21525	31975	8.2	66
"	6 days "	25325	34800	8.7	72
"	10 " "	26825	34725	8.0	75
"	14 " "	27550	35425	7.5	77
"	21 " "	26300	35300	7.8	75
"	31 " "	29025	35350	5.0	77
"	36 " "	29050	34900	5.7	81
"	60 " "	28600	35800	6.5	78
"	70 " "	28650	34600	5.3	78

*The analysis of these bars was as follows: 0.38%Cu, 0.17%Fe, 0.08%Si, 6.88%Zn, 0.12%Ti, 0.27%Mg, 0.23%Cr.

**These test bars were placed in boiling water. The resulting extremely slight corrosion after long exposure probably has contributed to the apparent adverse aging effect under these conditions.

TABLE IV

THE TENSILE PROPERTIES OF AN Al-Zn-Mg-Cu-Cr-Ti ALLOY* IN SEPARATELY CAST TEST BARS AND IN HEAVY SECTIONS POURED FROM 1350°F AND AGED 1 YEAR AT 85°F

Heat No.	Aging Treatment	Casting	Section Thickness Inches	Y.S. Min.	Y.S. Ave.	T.S. Min.	T.S. Ave.	% El. Min.	% El. Ave.	BHN Ave.
366	1 year at 85°F	6-bar	0.5	24600	24750	36000	37600	7.5	8.8	74
		step	1.0	22000	22300	26750	30450	2.5	5.5	70
		"	2.0	20600	21500	34200	37200	11.5	16.2	74
		"	4.0	14550	18600	22500	32900	7.5	16.2	69
365	1 year at 85°F	6-bar	0.5	25400	25600	38300	39450	8.5	9.6	80
		step	1.0	23300	23550	34700	35800	7.5	17.7	74
		"	2.0	16850	17900	31700	32900	13.0	14.6	68
		"	4.0	13400	17500	16150	30400	3.5	9.6	68
413	60 days at 85°F	6-bar	0.5	19100	19600	35800	36100	12.5	14.4	72
		step	1.0	18900	19500	32100	33400	9.5	10.5	70
		"	2.0	18500	20100	33100	36600	11.0	15.7	71
		"	4.0	18900	19900	32800	35700	9.0	13.9	70

*The analyses are as follows:

Heat No.	%Cu	%Fe	%Si	%Zn	%Ti	%Mg	%Cr
366	0.33	0.17	0.08	7.08	0.16	0.30	0.26
365	0.34	0.17	0.08	7.02	0.18	0.33	0.26
413	0.27	0.23	0.10	7.00	0.18	0.26	0.25

TABLE V

THE HIGH TEMPERATURE PROPERTIES OF CAST TEST BARS OF AN ALLOY CONTAINING 1.06% Cu, 0.16% Fe, 0.08% Si, 6.89% Zn, 0.13% Ti, 0.26% Mg and 0.27% Cr

Temperature	Time at Temperature	Y.S.	T.S.	%El.	BHN*
Room	6 months	27800	38400	5.5	82
200°F	1/2 hour		32100	10.5	66
"	3 days		33450	8.5	71
"	10 days		35800	5.0	79
"	25 "		37900	4.5	86
"	50 "		37800	3.5	86
"	100 "		36400	3.5	91
300°F	1/2 hour		25800	9.5	58
"	4 days		29100	6.5	78
"	9 days		27000	8.0	68
"	25 "		23700	8.0	62
"	50 "		22200	9.5	59
"	100 "		20700	8.0	49
400°F	1/2 hour		19700	10.5	56
"	2 days		14570	13.5	49
"	5 days		13650	16.5	48
"	10 "		12500	18.5	45
"	25 "		12250	18.0	45
"	50 "		11800	15.5	41
500°F	1/2 hour		11300	23.0	49
"	3 days		8700	33.0	43
"	5 days		8300	20.0	43
"	10 "		8550	30.0	41
"	25 "		8050	28.0	43
"	50 "		7800	33.0	40
600°F	1/2 hour		6400	29.0	42
"	1 day		6000	41.0	40
"	5 days		5500	32.0	41
"	10 "		5500	38.0	40
"	15 "		5400	39.0	39
"	25 "		5500	39.0	42

*Brinell Hardness tests were made at room temperature, after the high temperature treatment indicated in the table.

TABLE VII

THE EFFECT OF EXPOSURE TO BRAZING TEMPERATURES AND REAGING AT ROOM TEMPERATURE.
TESTS MADE ON CAST TEST BARS CONTAINING
0.38% Cu, 0.17% Fe, 0.08% Si, 6.87% Zn, 0.11% Ti, 0.26% Mg, 0.23% Cr

Treatment	Y.S.	T.S.	%El.	BHN
31 days at 85°F	20300	35600	10.5	66
26 days at 85°F, 2 hours at 900°F, + 30 days at 85°F	19500	33600	9.0	64
" " " " " " " 950°F, " " " " "	19500	33450	9.1	63
" " " " " " " 1000°F, " " " " "	19500	32700	8.0	67
" " " " " " " 1050°F, " " " " "	19600	34650	11.0	68
" " " " " " " 1100°F, " " " " "	19900	35800	12.9	67
" " " " " " " 1120°F, " " " " "	19300	35200	13.1	66

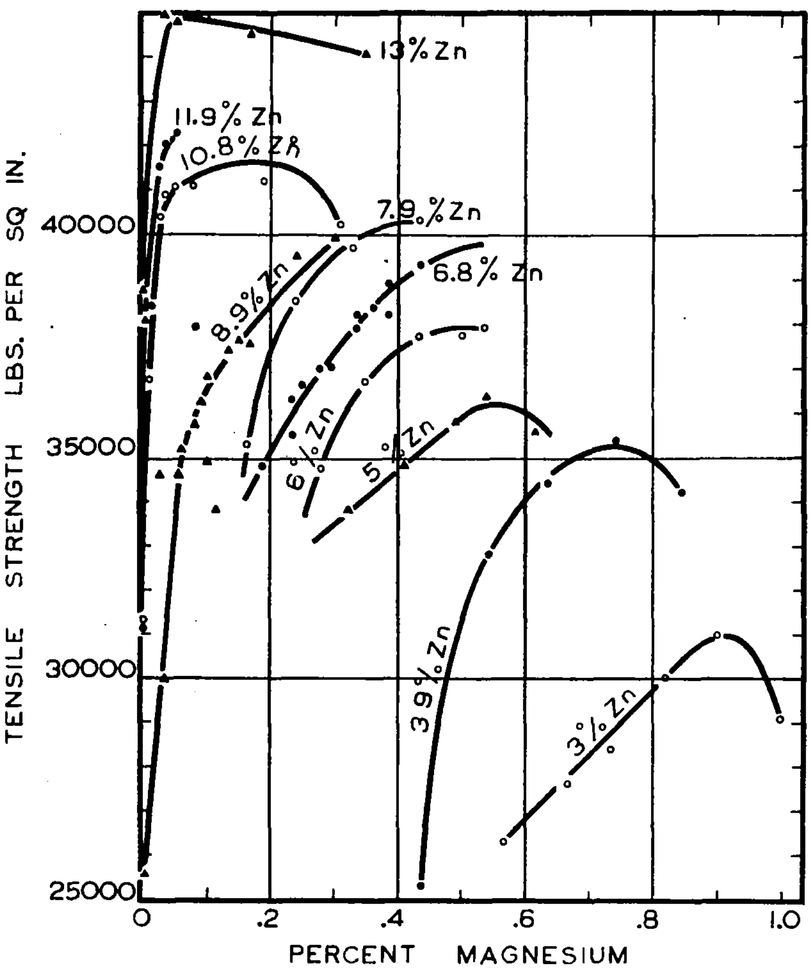

Figure 1a.- The effect of magnesium content on the tensile strength of alloys containing approximately 0.4% copper, 0.15% iron, 0.08% silicon, 0.25% chromium, and various amounts of zinc. All alloys as cast and aged 30 days at 85°F.

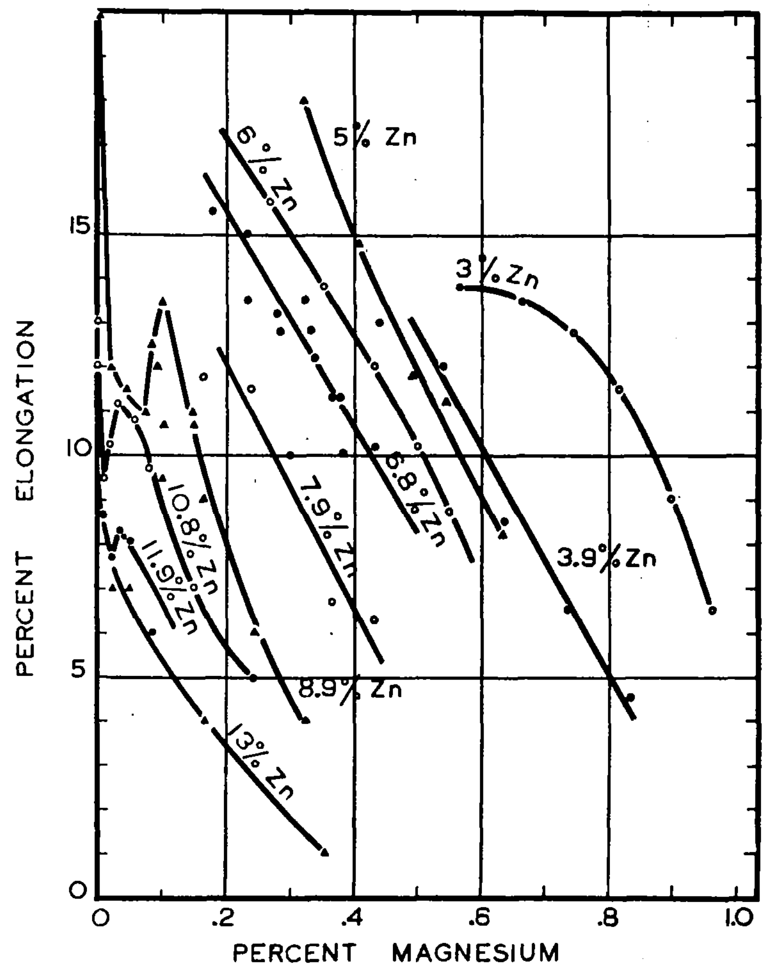

Figure 1b.- The effect of magnesium content on the percent elongation in 2 inches of gage length of alloys containing approximately 0.4% copper, 0.15% iron, 0.08% silicon, 0.25% chromium, and various amounts of zinc. All alloys as cast and aged 30 days at 85°F.

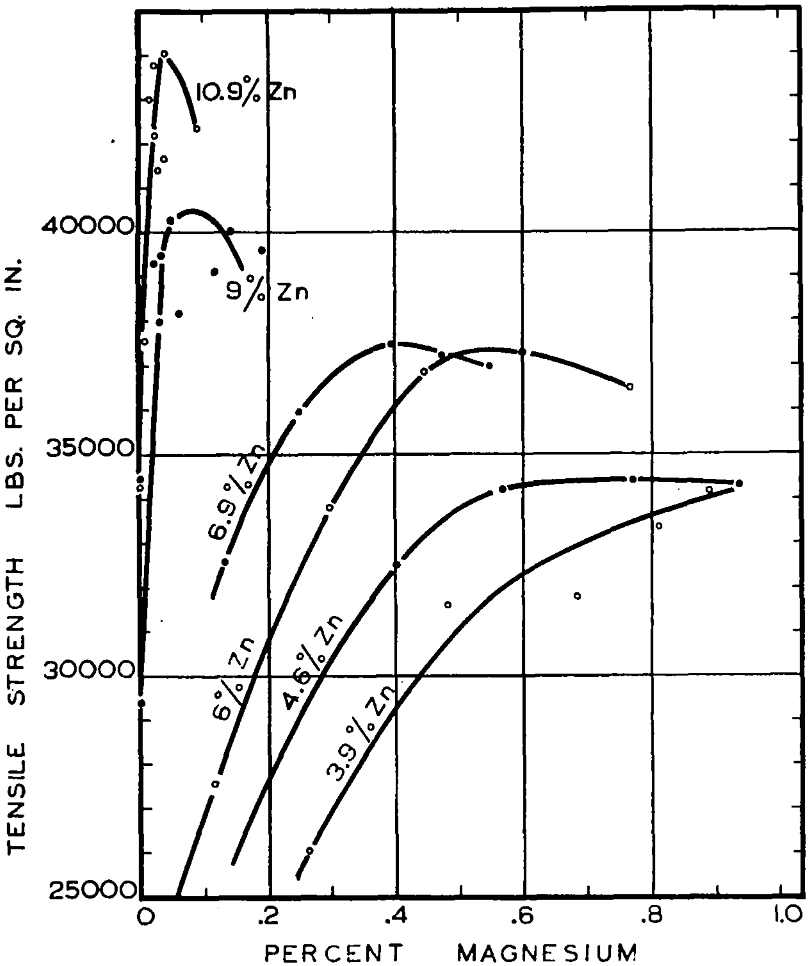

Figure 2a.- The effect of magnesium content on the tensile strength of alloys containing approximately 1.0% copper, 0.15% iron, 0.08% silicon, 0.25% chromium, and various amounts of zinc. All alloys as cast and aged 30 days at 85°F.

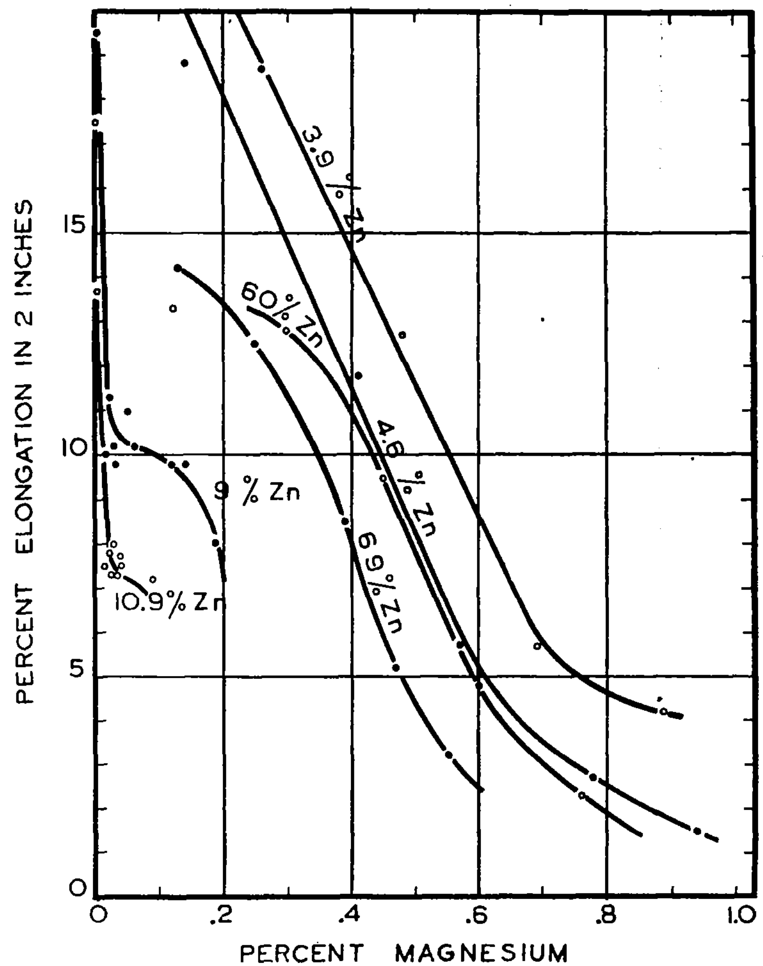

Figure 2b.- The effect of magnesium content on the percent elongation in 2 inches of gage length of alloys containing approximately 1.0% copper, 0.15% iron, 0.08% silicon, 0.25% chromium, and various amounts of zinc. All alloys as cast and aged 30 days at 85°F.

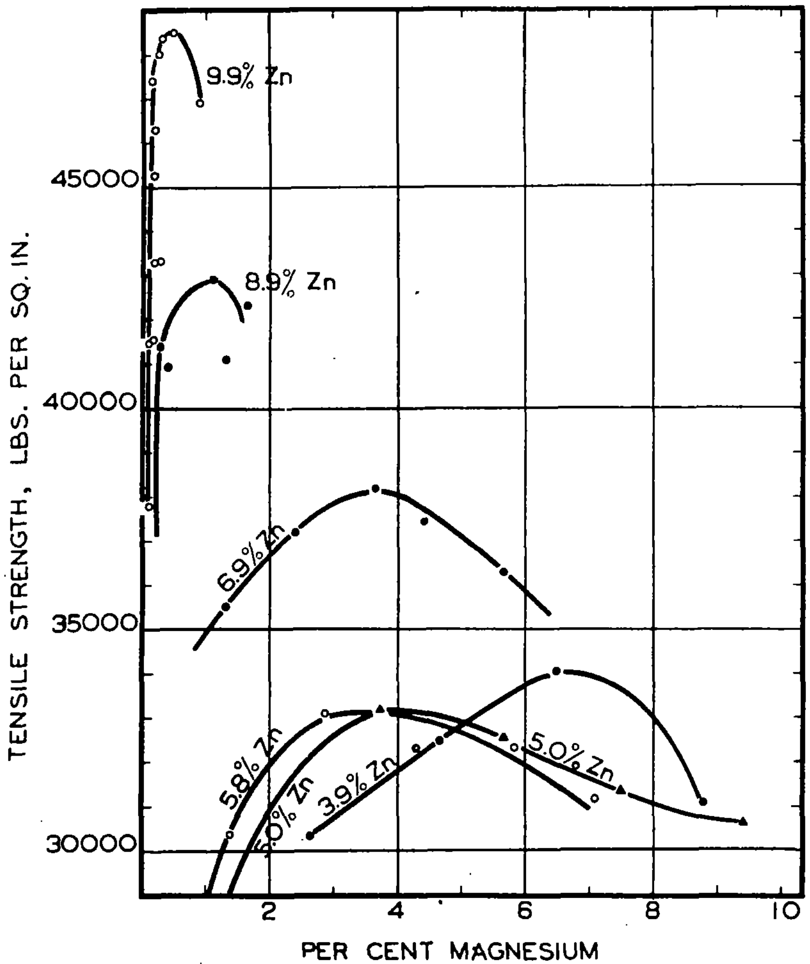

Figure 3a.- The effect of magnesium content on the tensile strength of alloys containing approximately 1.75% copper, 0.15% iron, 0.08% silicon, 0.25% chromium, and various amounts of zinc. All alloys as cast and aged 30 days at 85°F.

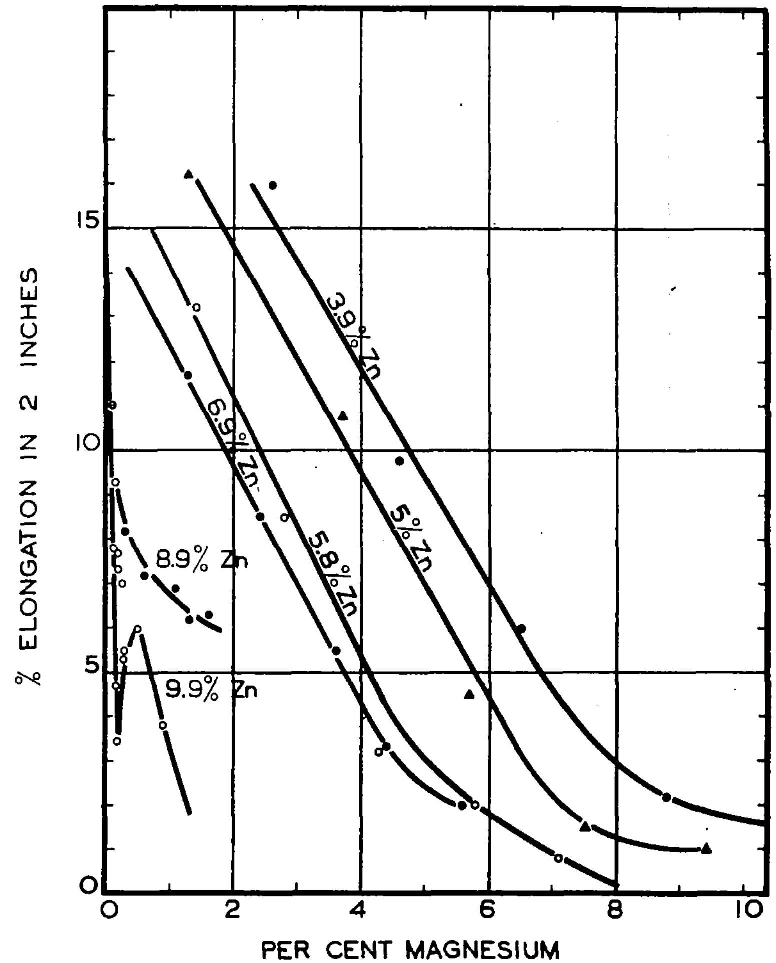

Figure 3b.- The effect of magnesium content on the percent elongation in 2 inches of gage length of alloys containing approximately 1.75% copper, 0.15% iron, 0.08% silicon, 0.25% chromium, and various amounts of zinc. All alloys as cast and aged 30 days at 85°F.

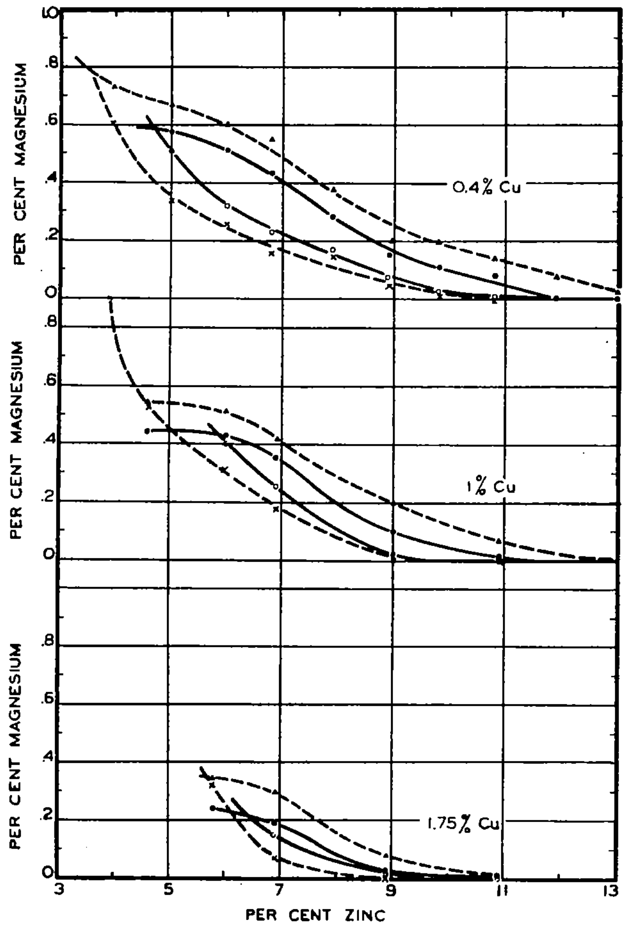

Figure 4.- The inside area represents the range in magnesium and zinc contents of cast test bars which will generally attain, after aging 30 days at 85°F, a minimum tensile strength and elongation of 36,000 pounds per square inch. and 10 percent respectively. The composition represented by the outside dashed lines will generally produce a minimum of 34,000 pounds per square inch and 7 percent elongation. These data are for aluminum alloys containing 0.15% iron, 0.08% silicon, 0.15% titanium, and 0.25% chromium and the copper, magnesium and zinc contents indicated on the chart.

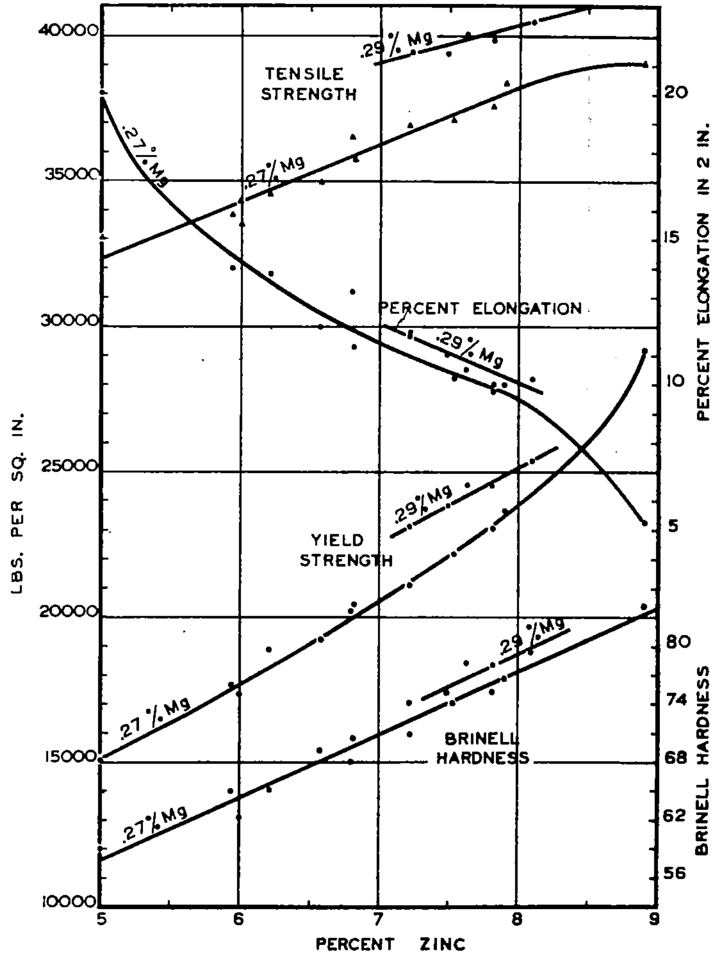

Figure 5.- The effect of zinc content on the tensile properties and hardness of cast test bars of aluminum alloys containing approximately 0.35% copper, 0.18% iron, 0.08% silicon, 0.13% titanium, 0.28% chromium, and 0.27% and 0.29% magnesium. All alloys aged 30 days at 85°F.

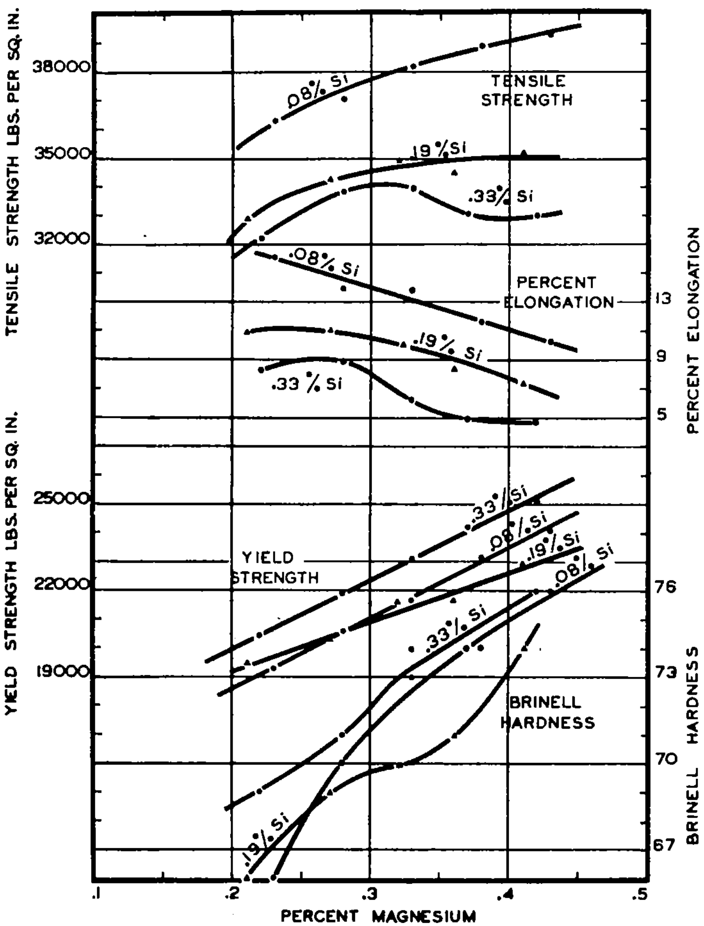

Figure 6.- The effect of magnesium content on the tensile properties and hardness of cast test bars of aluminum alloys containing approximately 0.38% copper, 0.15% iron, 6.6% zinc, 0.13% titanium, 0.22% chromium, and 0.08, 0.19, and 0.33% silicon. All alloys aged 30 days at 85°F.

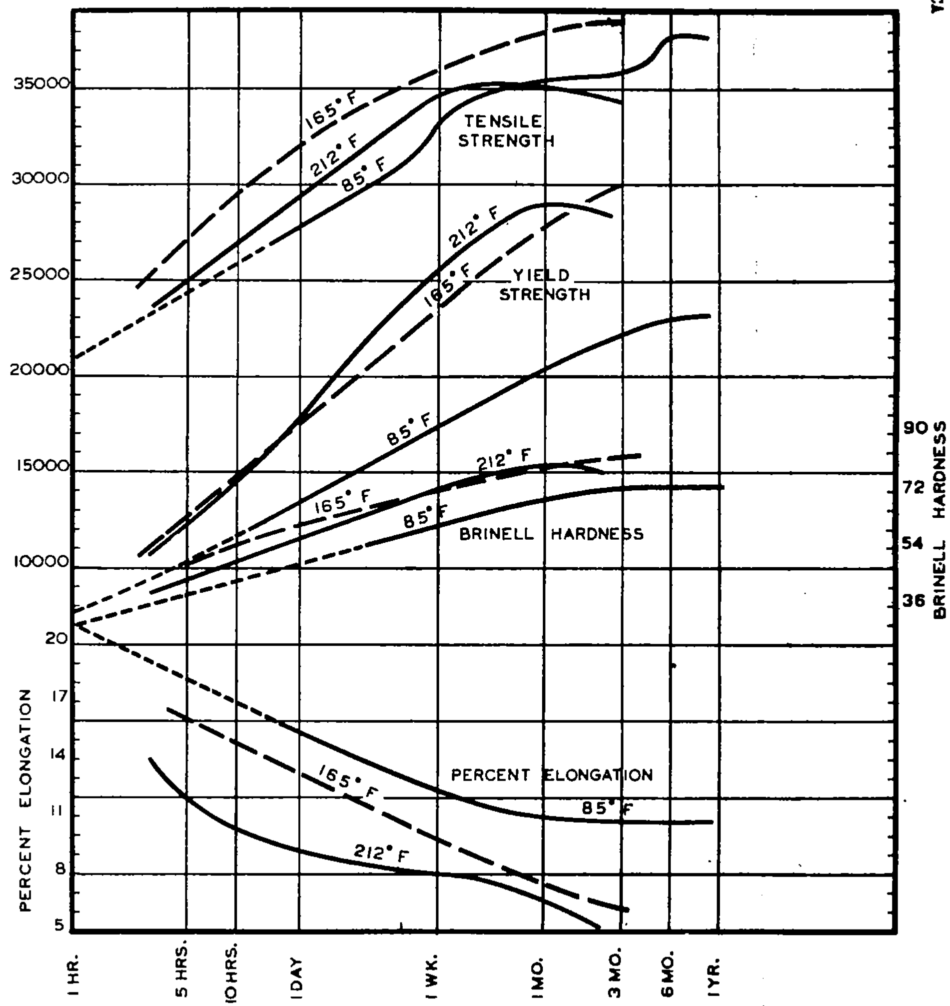

Figure 7.- The effect of aging time at 85°F, 115°F, and 212°F on the tensile properties and hardness of cast test bars of an aluminum alloy containing 0.38% copper, 0.17% iron, 0.08% silicon, 6.88% zinc, 0.12% titanium, 0.27% magnesium, 0.23% chromium.

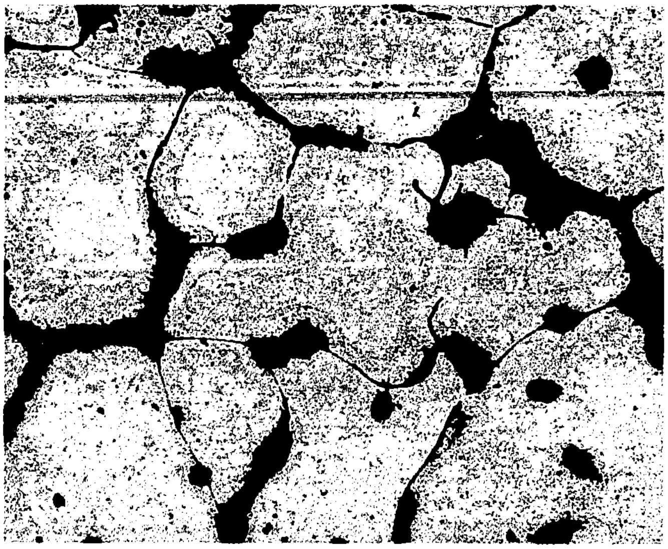

FIG. 8a Photomicrograph at X100 of an alloy containing 1.05% Cu, 0.15% Fe, 0.13% Si, 7.02% Zn, 0.14% Ti, 0.29% Mg and 0.30% Cr. Keller's etch.

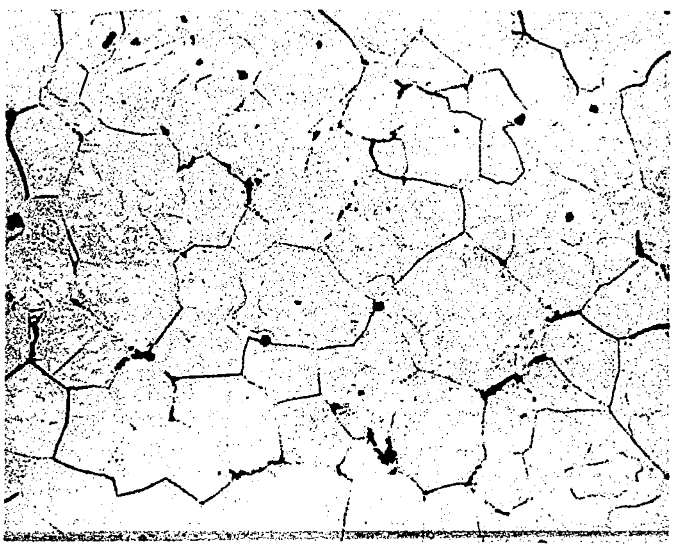

FIG. 8b Photomicrograph at X100 of an alloy containing 0.34% Cu, 0.17% Fe, 0.08% Si, 7.02% Zn, 0.18% Ti, 0.33% Mg and 0.26% Cr. Keller's etch.

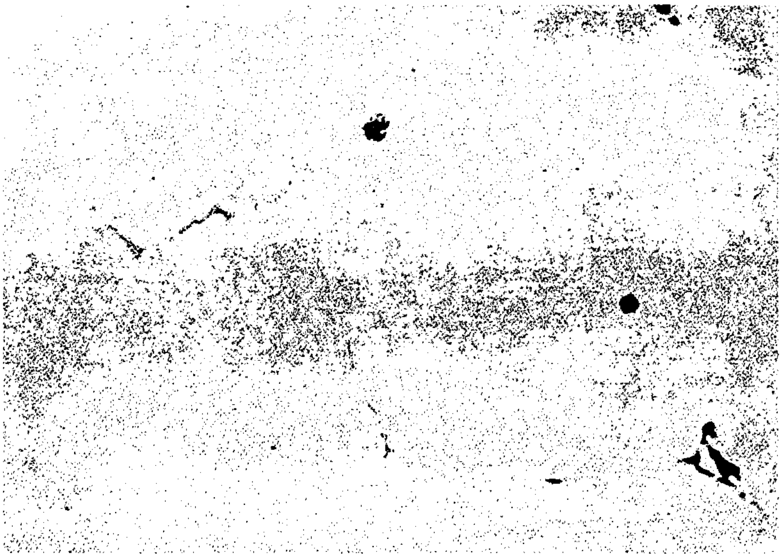

FIG. 8c Photomicrograph at X500 showing the elongated irregular gray constituent αAl-Fe-Si. The rounded light gray constituent is $CuAl_2$ rosettes. Unetched. Composition similar to that illustrated by Fig. 8b.

FIG. 8d Same as Fig. 8c. Etched with 10% NaOH solution in water. The $CuAl_2$ rosettes are light and the αAl-Fe-Si constituent is black.

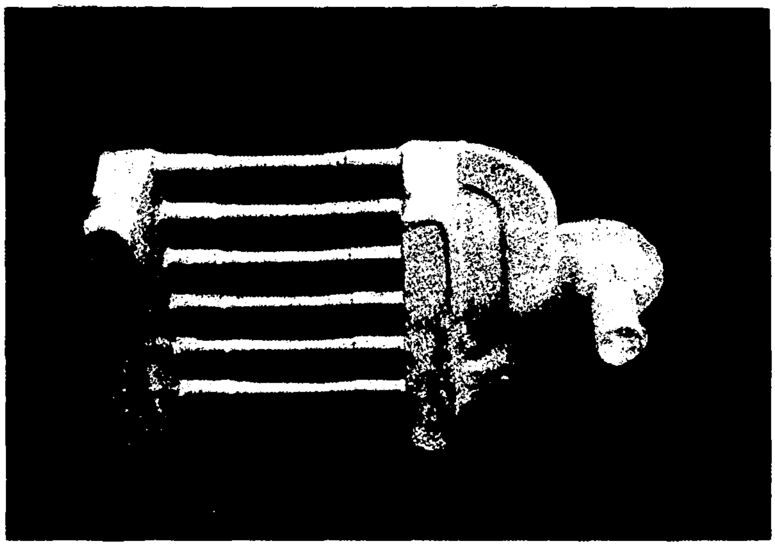

FIG. 9 The Six Bar Casting with Gate and Risers Attached.

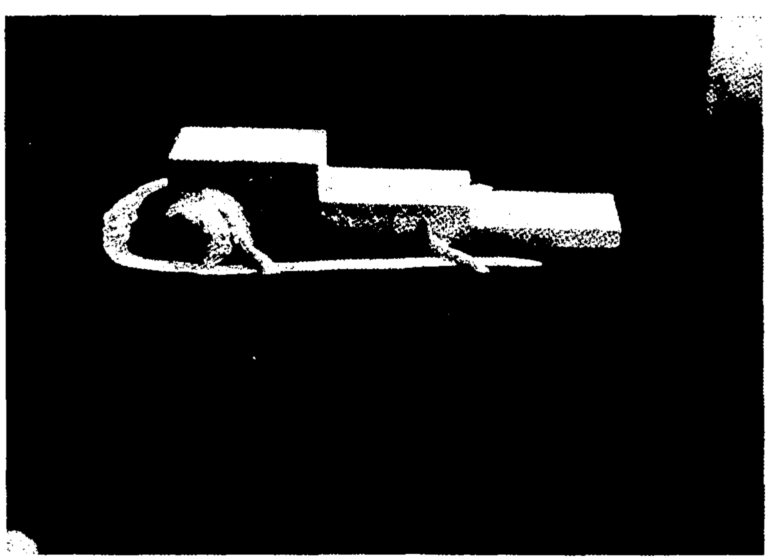

FIG. 10. The Step Casting with Gate and Risers Attached.